The effect of acute caffeine ingestion on repeated upper body anaerobic exercise and cognitive performance

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Abstract

The current study examined the effect of acute caffeine ingestion on mean and peak power production during upper body Wingate test (WANT) performance, rating of perceived exertion, readiness to invest effort and cognitive performance. Using a double-blind design, 12 males undertook upper body WANTs, following ingestion of caffeine ($5mg*kg^{-1}$) or placebo. Pre-substance ingestion, 60mins post substance ingestion and post exercise participants completed measures of readiness to invest physical and mental effort and cognitive performance. Peak power was significantly higher (P=.026), fatigue index greater (P=.02) and rating of perceived exertion lower (P=.025) in the presence of caffeine. Readiness to invest physical effort was also higher (P=.016) in the caffeine condition irrespective of time point (pre, 60 mins post ingestion and post exercise). Response accuracy for incongruent trials on the Flanker task was superior in the presence of caffeine (P=.006). There was a significant substance X time interaction for response speed in both congruent and incongruent conditions (both P= .001) whereby response speeds were faster at 60mins post ingestion and post exercise in the caffeine condition, compared to placebo. This is the first study to examine the effects of caffeine ingestion on this modality of exercise and suggests that caffeine ingestion significantly enhances peak power, readiness to invest physical effort, and cognitive performance during WANT performance.

Keywords: Wingate test; high-intensity exercise; cognition; ergogenic aid; nutrition.

Introduction

The positive effects of caffeine ingestion on exercise performance are well established (Graham, 2001; Astorino and Roberson, 2010), and although beneficial effects on aerobic exercise are well reported, there is greater ambiguity with respect to tests requiring anaerobic components of performance (Davis and Green, 2009). This has resulted in an increasing interest in caffeine responses to tests requiring maximal strength and power (Grgic and Mikulic, 2017), resistance exercise to failure (Astorino and Roberson, 2010) and the Wingate anaerobic test (WANT, Greer, McLean, & Graham, 1998; Salinero, et al., 2017). Despite this increased interest, results remain equivocal (Grgic, 2018). In the context of WANT performance, some studies have reported ergolytic effects (Greer, et al., 1998), others have reported significantly increased peak and mean power output following caffeine ingestion, compared to placebo (Salinero, et al., 2017). Recognising the equivocality on this topic, Grgic (2018) presented meta-analytical data examining the effects of caffeine ingestion on anaerobic exercise. Based on the available studies they concluded that acute caffeine ingestion, in the range 3-6 $mg*kg^{-1}$, augments lower body peak and mean power produced during the WANT. Standardised mean differences were moderate to small in magnitude for peak and mean power respectively.

Importantly, the meta-analysis by Grgic (2018) noted that none of their included studies assessed the effectiveness of blinding and no studies examined the effect of caffeine ingestion on upper body WANT performance (Grgic, 2018). Despite previous work demonstrating caffeine induced increases in upper body strength (Black, Waddell, and Gonglach, 2015), there is evidence to suggest that the effects of caffeine may not be uniform across the upper and lower body (Grigic and Mikulic, 2017; Tallis and Yavuz, 2018). It is also not necessarily appropriate to compare upper body maximal voluntary contraction data to more dynamic modes of anaerobic exercise (Black, et al., 2015). It has been suggested that in smaller muscle masses, such as muscles of the upper arm, there may be a limited ability for increased motor

unit recruitment associated with caffeine ingestion (Warren, Park, Maresca, McKibans, & Millard-Stafford, 2010).

In addition to physiological effects, caffeine ingestion influences a number of other psychological variables including rating of perceived exertion (Doherty, and Smith, 2005), readiness to invest effort (Duncan, Stanley, Parkhouse, Cook, & Smith, 2013) and cognitive performance (Nehlig, 2010, Einother and Giesbrecht, 2013, Van Duinen, Lorist, & Zijdewind, 2005). This is particularly the case for tasks that require performance on attentional tasks (Einother and Giesbrecht, 2013). No study to date has examined whether caffeine impacts these psychological variables during or post upper body anaerobic exercise. As both caffeine and exercise can independently influence the aforementioned variables (Einother and Giesbrecht, 2013, Duncan, et al., 2013) using a pre and post exercise design only enables the understanding of if caffeine and exercise had any effect. In such circumstances it is prudent to assess the effect of caffeine independently to exercise by employing a pre ingestion, post ingestion but pre exercise and post exercise design (Duncan, et al., 2013). Understanding if caffeine influences these variables is important as responses to upper body exercise for these variables differ to that of lower body exercise. Assuming caffeine ingestion has the same effect on upper body performance as it does on the lower body may lead to erroneous conclusions regarding the effect of caffeine on performance. For example, perception of exertion may be amplified during upper body exercise (Kang, Chaloupka, Mastrangelo, & Angelucci, 1999) as less extraneous sensory information is processed when using a smaller muscle mass (Pandolf, Billings, Drolet, Pimental, & Sawka, 1984) and cerebral blood flow is greater for upper body, compared to lower body exercise (Thomas, Schroeder, Secher, & Mitchell, 1989) with greater increases in catecholamines (Davies, Few, Foster, & Sargeant, 1974). Such changes should theoretically facilitate speed of processing, particularly during attentionally demanding tasks (McMorris, Sproule, Turner, & Hale, 2011). Given the extant literature on effect of caffeine on exercise performance and responses to upper body exercise separately, it would be hypothesised that acute caffeine ingestion would enhance peak and mean power

output during anaerobic exercise tests, dampen perceived exertion and enhance readiness to invest effort and cognitive performance, compared to placebo.

The current study sought to address a key gap in the literature by investigating the effect of acute caffeine ingestion on mean and peak power production during WANT performance, rating of perceived exertion, readiness to invest effort and cognitive performance.

Methods

Participants

Following institutional ethics approval and informed consent, 12 males (aged 18-30; 21.4±4.4 years; height 173±0.8cm; body mass 76.2±12.9kg; mean±SD) agreed to participate. All participants habitually ingested caffeine although none were heavy caffeine users (mean ± SD of caffeine consumption = 154.3 ± 40.6 mg/day, range = 97-240 mg/day). Caffeine intake was established using a 24-hour recall questionnaire (Maughan, 1999) and heavy caffeine use was established using cut-points proposed by Smit & Rogers (2000). All participants completed a health history questionnaire to ensure that they were 'apparently healthy' and accustomed to regular high-intensity exercise. Participants were excluded if they had a musculoskeletal injury or cardiovascular condition that restricted exercise performance or were a heavy habitual caffeine user.

Procedures

All testing took place between 9.00am and 12.00noon with each condition taking place at the same time of day for each participant. Participants were asked to refrain from vigorous exercise, maintain normal dietary patterns in the 48h prior to testing and were asked not to

consume caffeine after 6:00pm the night before testing (Marlat and Rosenhow, 1980). Participants were also asked to maintain the same exercise, hydration, sleep and dietary habits between visits and verbally confirmed this was the case. Each participant undertook 3 visits to the human performance laboratory. In the first visit they were familiarised with the equipment and procedures involved in the study. In the following two experimental trials participants undertook upper body, WANTs, following ingestion of either caffeine or placebo.

Prior to the experimental trials, participants ingested either 5 $mg*kg^{-1}$ body mass of caffeine (Myprotein, UK) or a placebo (5 $mg*kg^{-1}$ dextrose, Myprotein, UK) administered in gelatine capsules with 200ml water. Substances were presented double blind and in a counterbalanced order. Substances were consumed 60 minutes before each exercise trial as plasma caffeine concentration is maximal 1 hour after ingestion of caffeine (Graham, 2000).

Exercise Protocol and Performance Measures

The exercise test consisted of a 30 second upper body WANT, completed on a Monark Peak bike (Ergomedic 894E, Vansbro, Sweden) and executed following recommended guidelines (Peterson, 2012). The ergometer was calibrated prior to any testing. A fly wheel braking force corresponding to 0.05kg/per kg body mass (Nindl, Mahar, Harman, & Patton, 1995) was used. Prior to the test commencing, participants completed a 4-minute warm up at a self-selected pace, interspersed with short sprints (5 seconds) of maximal arm cranking. After a short gap (approx. 1 minute), the participant was then asked to begin cranking at maximal cadence against no load. Once the participant was at maximal cadence the external load was applied for a duration on 30 seconds. Care was made to ensure participants remained seated throughout. The peak power output, mean power output, and fatigue index (%) were calculated during the WANT using custom software sampling data at 0.5 second intervals. Peak power was defined as the highest power output achieved during any 0.5 second interval and mean power was defined as the average power over the 30 second test.

Fatigue index was determined as the percentage difference between maximal and minimal performance over the 30s test.

Peak heart rate (PHR) was assessed using heart rate telemetry (Polar Electro Oy, Kempele, Finland) and on completion of each test, rating of perceived exertion (RPE) for the active musculature was determined using the Borg 6-20 RPE scale (Borg, 1970). This is in accordance with protocols used to assess RPE following Wingate testing and caffeine ingestion (Woolit is importantf, Bidwell, & Carlson, 2008). Peak blood lactate (PBla) was also determined 3 minutes after each test using a capillary blood sample from the earlobe (Lactate Plus, Nova Biomedical, USA).

Pre-substance ingestion, 60mins post substance ingestion and post exercise participants completed measures of readiness to invest physical effort (RTIPE) and readiness to invest mental effort (RTIME) and cognitive performance. In this way we sought to assess the effect of the substance ingested independent of, and in addition to, the exercise bout.

Readiness to invest physical and mental effort was scored on visual analogue scales ranging from 0-100mm with higher scores reflecting greater readiness to invest effort. These measures were based on recommendations for assessing perceived readiness to invest effort in exercise testing (Tenenbaum et al., 2005).

Cognitive performance was assessed using a modified flanker task (Eriksen and Eriksen, 1974; Hillman et al., 2006; Pontifex and Hillman, 2007). Participants completed the trials on a Sony Laptop computer (Sony Vaio, Sony Inc, Japan) via open source experimental software (Mathôt, Schreij, & Theeuwes, 2012). Congruent and incongruent trials required participants to press a button corresponding to the direction of a centrally presented target arrow. Congruent trials consisted of an array of five arrows facing the same direction (e.g. <<<<< or >>>>>) and incongruent trials consisted of the four flanking arrows facing the opposite direction to that of the target arrow (e.g. <<><< or >><>>). Following the provision of task instructions, participants were afforded the opportunity to ask questions and 20 practice trials were administered prior to the start of testing in line with prior procedures (Pontifex and

Hillman, 2007). The experimenter observed participants during the practice trials and checked their performance to ensure that they understood the task. Within each condition (caffeine vs. placebo) and at each time point (Pre-substance ingestion, 60mins post substance ingestion and post exercise), participants were administered 100 trials, consisting of equiprobable congruency and directionality. Stimuli were 2.5cm tall white arrows presented focally for 120ms on a black background with a response window of 1000ms and a variable inter-stimulus interval of 1100, 1300, or 1500ms. Total task duration was approximately 3 min. This task then allowed calculation of measures of response speed and response accuracy.

Assessment of Blinding

After completion of all trials, participants were asked which trial they thought was the caffeine and which the placebo trial. They were also asked to outline why they identified which trial as which. These responses were noted down by the researchers to address criticisms of past studies on the effect of caffeine which have not assessed the efficacy of blinding (Grgic, 2018).

Statistical analysis

In order to examine whether there were any differences in peak power, mean power, fatigue index, PBla, PHR and RPE between caffeine and placebo conditions a series of paired t-tests were carried out. For RTIPE, RTIME and accuracy and response time scores for congruent and incongruent trials on the flanker task, in order to examine if either of these measures changed pre-ingestion to post ingestion but pre exercise and to post exercise, each was analysed using a 3 (time, pre ingestion, post ingestion, post exercise) X 2 (substance) ways repeated measures ANOVA. Where any significant differences were found Bonferroni post-hoc pairwise comparisons were used to indicate where the differences lay. Partial eta^2 ($P\eta^2$) and Cohen's *d* were used as measures of effect size in the case of ANOVA and t-test analysis respectively. Given the limitations of data presentation using bar graphs

(Weissgerber, Milic, Winham, & Garovic, 2015), data were visually presented following procedures advocated by Weissgerber et al (2015) by presenting data distribution in figures to ensure more complete presentation of data. The statistical package for social sciences (SPSS Version 22) was used for all analysis.

Results

Mean ± SD and 95% CIs for peak power, mean power, fatigue index, PBla, PHR and RPE in caffeine and placebo conditions for each repetition of the upper body WANT are presented in Table 1.

Peak Power

Peak power was significantly higher (P = .026, *d* = .5) in the presence of caffeine compared to placebo. A Scatterplot showing the data distribution for peak power for the WANT in caffeine and placebo conditions is presented in Figure 1.

Figure 1 here

Mean Power

For Mean power there was no significant difference between caffeine and placebo conditions (P = .872, *d* = .02). A Scatterplot showing the data distribution for mean power for the WANT test in caffeine and placebo conditions is shown in Figure 2.

Figure 2 Here

Fatigue Index

Data for fatigue index indicated a significant difference between caffeine and placebo conditions (P = .02, *d* = .4) where fatigue index was higher in the caffeine condition compared to the placebo condition.

Blood Lactate, Peak Heart Rate and Rating of Perceived Exertion

For blood lactate there was no significant difference between caffeine and placebo conditions (P = .613, *d* = .2). The results for PHR followed a similar trend to those for blood lactate with no significant difference evident between caffeine and placebo conditions (P = .937, *d* = .04). RPE values were significantly different between caffeine and placebo conditions (P = .025, *d* = .6) where RPE was significantly lower in the presence of caffeine.

Readiness to Invest Effort

Mean ± SD for RTIPE and RTIME pre-ingestion, post ingestion but pre exercise in caffeine and placebo conditions are presented in Table 2. For RTIPE results indicated no significant substance X time interaction (P = .109) but there were significant main effects for substance ingested (P = .016, $P\eta^2$ = .423) and time (P = .004, $P\eta^2$= .398). Irrespective of time RTIPE was higher in the caffeine condition compared to placebo (P = .016). For the time main effect Bonferroni post hoc multiple comparisons indicated there was no significant difference for RTIPE pre-ingestion to 60mins post ingestion (P = .220) or between pre ingestion and post exercise (P = .272). However, RTIPE was significantly higher 60mins post ingestion compared to post exercise (P = .007). For RTIME, there was no significant substance X time interaction (P = .464) or main effects for substance ingested (P = .264) or time (P = .06).

Cognitive performance

Results from the flanker task for response accuracy indicated no significant substance X time interaction (P = .277) or main effects for substance (P = .115) or time (P = .483) for the congruent condition. For response accuracy in the incongruent condition there was also no significant substance X time interaction (P = .439) or main effect due to time (P = .098). There was however a significant main effect for substance ingested (P = .006, $P\eta^2$ = .510) whereby response accuracy was superior in the caffeine condition compared to the placebo condition.

In regard to response speed, results indicated a significant substance x time interaction (P = .001, $P\eta^2$ = .565) in the congruent condition. Bonferroni post-hoc pairwise comparisons indicated no significant differences in response time between caffeine and placebo conditions pre-ingestion (P = .183), but significantly faster response speed at 60mins post ingestion (P =.007) and post exercise (P = .002) in the caffeine condition compared to the placebo condition. For the caffeine condition there was also significantly faster response times at 60mins post ingestion (P =.001) and post exercise (P = .032) compared to pre-ingestion. In the placebo condition there was significantly faster response time at 60mins post ingestion compared to post exercise (P = .008) and a non-significant trend (P = .054) for faster response time at 60mins post ingestion compared to pre-ingestion.

When response speed was examined for the incongruent trials the results mimicked those for congruent response speed. There was a significant substance x time interaction (P = .001, $P\eta^2$ = .579). Bonferroni post hoc pairwise comparisons indicated no significant differences in incongruent response times between caffeine and placebo conditions pre-ingestion (P = .363) or 60mins post ingestion (P = .200). There was however significantly faster response times post exercise in the caffeine condition compared to the placebo condition (P = .002). For the caffeine condition there was also significantly faster response times at 60mins post ingestion (p =.013) and post exercise (p = .02) compared to pre-ingestion. In the placebo condition there was significantly faster response time at 60mins post ingestion compared to post (P = .011). Mean ± SD for congruent and incongruent response

accuracy and speed pre-ingestion, 60mins post ingestion in caffeine and placebo conditions are presented in Table 2.

Efficacy of Blinding

Post experiment responses in regard to participant awareness of which trial involved caffeine and which placebo indicated that five participants (42%) correctly identified the caffeine trial and placebo trials, suggesting that they felt ‘more alert’, ‘more aware’, ‘ready to go’ and in one case that their ‘muscles were tingling’ in the caffeine trial compared to the placebo. Conversely another five participants (42%) incorrectly identified the correct trial, suggesting similar responses to those of the correct participants for why they thought the placebo trial was the caffeine trial. Two participants (16%) stated they could not judge which trial was which.

Discussion

The results of the current study suggest that caffeine ingestion significantly enhances peak power, but not mean power output during upper body anaerobic exercise and, at the same time enhances cognitive performance, dampens RPE and increased readiness to invest physical effort. This is the first study to examine the effects of caffeine ingestion on this modality of exercise and thus makes a novel contribution to the literature.

It is important to determine if the responses to caffeine ingestion for upper body exercise are similar to those reported for their lower body equivalents to avoid making erroneous assumptions. As such this work extends understanding in the area. The caffeine induced increased peak power, but unaffected mean power suggests faster fatigue, supported by the significantly greater fatigue index compared to the placebo trial. It is somewhat difficult to compare the current findings to prior work as no study has examined the effect of caffeine

ingestion on upper body WANT performance. Current findings broadly agree with assertions made regarding effects of caffeine on lower body WANT performance (Grgic, 2018, Duncan, 2009; Salinero, et al., 2017; Greer, et al., 1998). Likewise, the lack of difference in blood lactate post exercise is not unusual and has bene reported previously (Woolf, et al., 2008). The results of the present study support this work. However, other research has suggested that caffeine ingestion increases blood lactate production (Glaister, Williams, Muniz-Pumares, Balsalobre-Fernandez, & Foley, 2016) and/or impairs lactate clearance (Glaister, et al., 2016). This suggestion is contrary to the findings of the current study. These contradictory results may be because only caffeine was ingested and the nature of the blood lactate response to submaximal exercise in the presence of caffeine has been acknowledged as equivocal (Glaister et al., 2016). The blood lactate response to anaerobic exercise in the presence of caffeine is less clear and additional research is required to better understand the blood lactate response to high intensity anaerobic exercise after caffeine ingestion.

The lack of a caffeine effect on upper body exercise performance has been attributed to a lack of familiarity in upper body maximal exercise assessments (Tallis and Yavuz, 2018), and reduced caffeine induced mechanistic activation of the smaller muscles groups of the arm compared to larger lower body muscle groups (Warren, et al., 2010). While this may be the case in upper body exercises such as the bench press (e.g., Grigic and Mikulic, 2017), by virtue of the requirements of the upper body WANT there is likely greater contribution to the exercise of the abdominals, back, and chest as well as the arms. Green et al (2007) also suggested there may be a threshold of total volume of muscle activity where the effects of caffeine become apparent. As such the results of the present study suggest that the assertion made by Warren et al (2010) may not hold for the upper body WANT and the results presented here represent an advancement of the understanding of caffeine ingestion on upper body performance.

The present study also suggests that caffeine ingestion dampens RPE compared to placebo. Such a finding is apparent in the literature across aerobic and anaerobically based

exercise modalities (Doherty and Smith, 2005; Duncan, et al., 2013). In line with suggestions by Tenenbaum et al (2005), the current study further examined if ingestion of caffeine influences how ready participants are to invest effort. In this study caffeine ingestion resulted in increased readiness to invest physical effort compared to the placebo condition. This is congruent with prior work by Duncan, Smith, & Cook (2012) which reported increased readiness to invest physical effort after ingestion of a caffeine containing energy drink. Unlike the present study, the work by Duncan et al (2012) also reported increased readiness to invest mental effort following ingestion of a caffeine containing energy drink. This may because only caffeine was ingested in the current study whereas in the Duncan et al (2012) study the energy drink participants consumed included ingredients (e.g., Taurine, Tyrosine) other than caffeine.

The results of the current study also align with assertions that caffeine positively influences cognitive performance (Nehlig, 2010, Einother and Giesbrecht, 2013, Van Duinen, Lorist, & Zijdewind, 2005). By examining cognitive performance pre-ingestion, 60mins post ingestion and post exercise, the current study was able to highlight the effect of caffeine ingestion alone and post exercise. An improvement in Flanker task performance because of the substance ingested was demonstrated. This is consistent with assertions made by Einother & Giesbrecht (2013) that caffeine is an attentional task enhancer and offsets the detrimental effects of high intensity exercise on cognitive performance (McMorris, et al., 2011) and is supportive of prior work by Van Duinen et al (2005) which also reported caffeine to offset fatigue related declines in cognitive performance.

There are some limitations of the current study. We acknowledge that control of sleep, exercise, hydration and dietary habits was based on participants monitoring their own behaviour and affirming that these habits did not change between trials. This may not however be the case and future research should attempt to quantify, and thus better control, these confounding variables between trials. Habitual caffeine consumption was also established by self-report, as is commonly used in the literature, however, it is possible self-report of this data may not match the actual. In the current study, dextrose was used as a placebo. Dextrose,

ingested on a chronic basis has been shown to enhance exercise performance (Dunne, Worley, & Macknin, 2006) but, in the current study volume of dextrose ingested is far lower than thresholds suggested to be ergogenic (Baker, Rollo, Stein, & Jeukendrup, 2015). However, the placebo employed in the present study is not entirely inert in terms of its effect on human performance. The Flanker task employed in the current study only assesses one facet of cognitive performance. Examining if caffeine ingestion has a similar impact on aspects of cognition would be beneficial in providing a more expansive overview of effects of caffeine on post exercise cognitive performance. The current study also examined young males who were involved in regular exercise but not specifically athletes. Future work examining if caffeine has the same effect on upper body WANT performance in females and trained athletes would also be useful. Concurrent assessment of potential effects of caffeine on upper and lower body anaerobic exercise performance and cognition would also extend the research presented in the current study.

To conclude, ingestion of 5 $mg*kg^{-1}$ body mass caffeine enhances peak power production, improves cognitive performance, dampens RPE and enhances readiness to invest physical effort during upper body WANTs in non-specifically trained males. Such results have application for sports where there may be upper body anaerobic power demands such as boxing, rowing and wheelchair sports. Given the enhanced cognitive performance identified in the present study, sports or occupational activity where there is a need for anaerobic performance concurrent with decision making (e.g., firefighting, military related tasks, wheelchair basketball) may benefit from acute caffeine ingestion.

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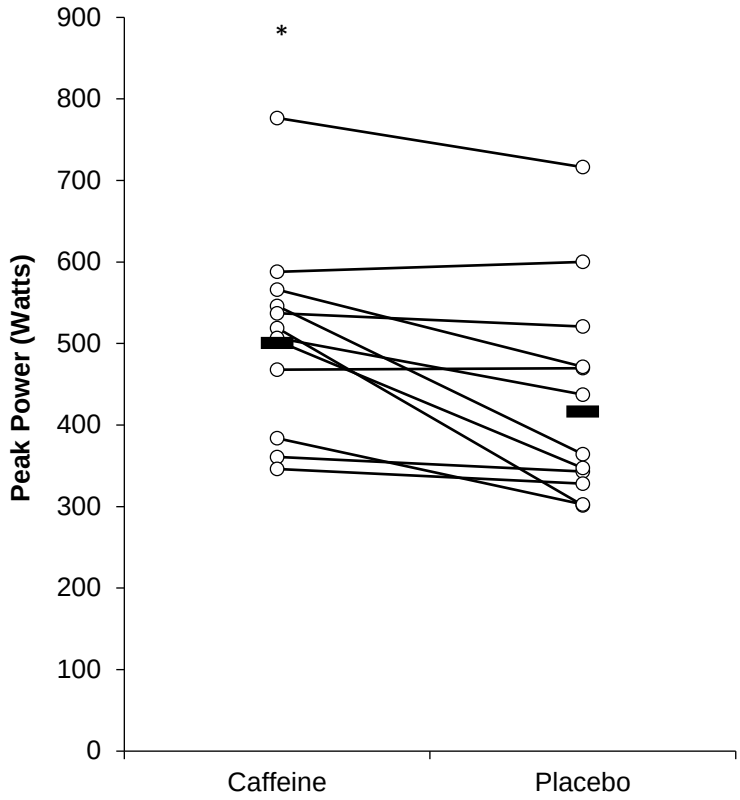

Figure 1. Scatterplot showing the mean (filled bar) and data distribution for peak power for the Wingate test in caffeine and placebo conditions where peak power was significantly (*p = .02) higher in the presence of caffeine.

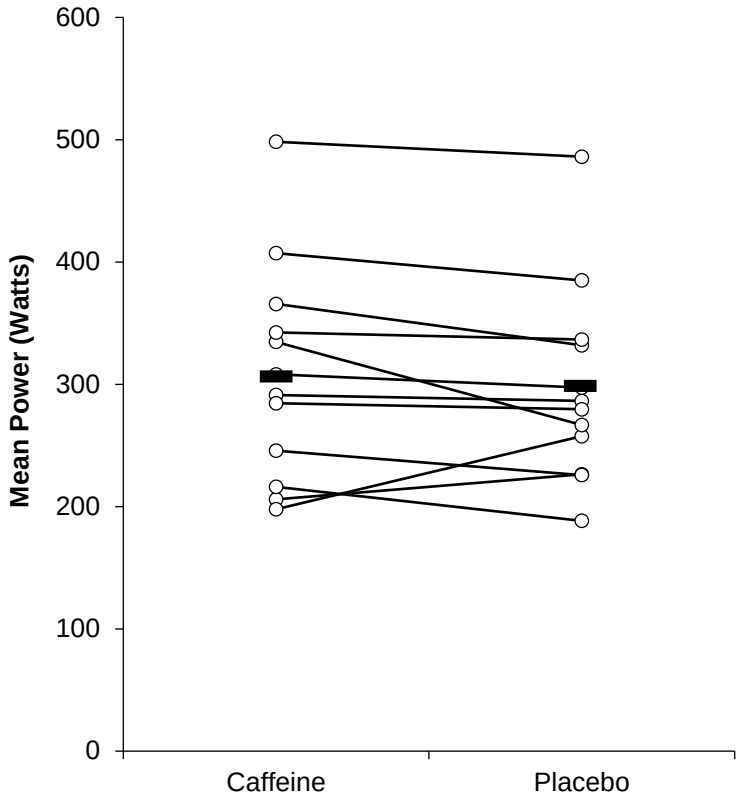

Figure 2. Scatterplot showing the mean (filled bar) and data distribution for mean power for the Wingate test in caffeine and placebo conditions where mean power was not significantly (P = .872) between conditions.